Evaluation of Radiation Exposure to the Patients Undergoing Positron Emission Tomography/Computed Tomography-Guided Biopsies

Abstract

Purpose: We aimed to evaluate the radiation exposure to patients undergoing positron emission tomography/computed tomography (PET/CT)-guided biopsies. **Materials and Methods:** Patients undergoing PET/CT-guided biopsy were recruited prospectively from October 2019 to April 2020. PET/CT-guided biopsy from a tracer avid site was done using an automated-robotic-arm 1 h after intravenous injection of F-18-fluorodeoxyglucose (FDG) (2-5 mCi) or Ga-68-PSMA (1–4 mCi). Regional CT-images were acquired for biopsy planning and confirmation of needle placement. The internal radiation exposure due to the PET component was estimated using the value of activity injected and dose-coefficient for FDG and PSMA. The external radiation exposure due to the CT component was estimated using the value of dose length product and organ coefficients conversion factor. The total effective dose during the procedure was calculated by adding exposure due to both CT and PET components. Percentage contribution from CT and PET component to total effective dose was compared using a paired t-test. **Results:** A total of 101 patients (76 males) were recruited for PET/CT-guided biopsy using FDG ($n = 79$) and PSMA ($n = 22$). The mean effective-dose due to PET and CT components and total effective-dose was 2.49 ± 1.02 mSv, 2.35 ± 1.03 mSv and 4.83 ± 1.90 mSv, respectively, for FDG-guided procedures and 1.60 ± 0.57 mSv, 3.06 ± 1.36 mSv, and 4.66 ± 1.37 mSv for Ga-68-PSMA-guided procedures. The percentage contribution of PET and CT in total effective-dose was comparable in F-18-FDG and Ga-68-PSMA PET/CT-guided biopsy procedures; however, for Ga-68-PSMA PET/CT-biopsies, CT contributed a higher radiation dose than PET component. **Conclusion:** PET/CT-guided biopsy is a safe interventional procedure, and radiation exposure to the patients was less than routine whole-body PET/CT-imaging.

Keywords: *Fluorodeoxyglucose F18, Glu-NH-CO-NH-Lys-(Ahx)-((68) Ga (HBED-CC)), image-guided biopsy, positron emission tomography computed tomography, radiation exposure*

Krishnapriya Deva, Nivedita Rana, Rajender Kumar, Bhagwant Rai Mittal

Department of Nuclear Medicine, Postgraduate Institute of Medical Education and Research, Chandigarh, India

Introduction

Positron emission tomography/computed tomography (PET/CT) is an established imaging modality in the metastatic workup of cancer patients.[1,2] In the past two decades, the role of this hybrid imaging modality has been extended to be a guiding tool in intervention procedures.[3-7] The wide acceptability of PET/CT as a guiding tool is due to the confidence offered by functional information from PET in addition to the anatomical information provided by CT. Functional information poses the advantage of getting tissue samples from a hypermetabolic part of the lesion, thus reducing the chances of false-negative biopsy results.[3,8] PET/CT-guided biopsies can be done either using an automated robotic arm that plans orientation of needle trajectory or with the help of fiducial markers using a helical CT or under CT fluoroscopy.[9-11] In either case, the positioning of the needle to the target lesion is checked by acquiring low-dose CT images (check CT scan). A robotic arm was used to target the lesions in a single pass and minimizes the need for multiple check CT scans.[10-12] It reduces the radiation exposure to the personnel performing biopsies and the patient undergoing the procedure.[13-15] The number of check CT scan varies depending upon the size of the lesion, its depth, and any vital structure in the vicinity of the lesion. With the increase in the number of check CT scans, radiation exposure to the patient undergoing biopsy increases from the CT component. Although it is justified to acquire multiple check CT scans to get conclusive biopsy results, radiation exposure in patients undergoing PET/CT guided biopsy is still a concern.

Access this article online

Website: www.ijnm.in

DOI: 10.4103/ijnm.ijnm_112_21

Quick Response Code:

How to cite this article: Deva K, Rana N, Kumar R, Mittal BR. Evaluation of radiation exposure to the patients undergoing positron emission tomography/computed tomography-guided biopsies. Indian J Nucl Med 2022;37:23-8.

The radiation exposure to patients during PET/CT-guided biopsy is due to both the CT component (routine CT and additional low dose check CT) and PET component. Assessment of radiation exposure to patients undergoing biopsies can give us an idea about the steps that can be taken care to reduce the exposure further. Although there have been few studies to estimate the radiation exposure to the personnel performing biopsies, no study to our knowledge has evaluated the radiation exposure to the patients.[16,17] Hence, the primary objective of this study was to estimate radiation dose to patients undergoing PET/CT-guided biopsy procedures.

Materials and Methods

In this prospective study, participants who underwent PET/CT guided biopsy were included from October 2019 to April 2020 for measuring the radiation exposure during the procedure. The study was approved by the Institutional Ethics Committee, and written informed consent was taken for the biopsy procedure, explaining the complications, benefits and risks. The inclusion criteria were tracer avid lesion on PET/CT scan with normal coagulation profile and aged more than 18 years. The exclusion criteria were abnormal coagulation profile, hemoglobin <8 mg/dl, and platelet <80,000/μl.

F-18-fluorodeoxyglucose positron emission tomography/computed tomography and Ga-68-PSMA imaging

All the patients fasted for at least four hours before PET/CT-guided biopsy. Regional PET/CT images of the target organ were acquired using a dedicated PET/CT scanner (Discovery MIDR, GE Healthcare, USA) after intravenous injection of the radiotracer (F-18-fluorodeoxyglucose [FDG]: 2–5 mCi or Ga-68-PSMA: 1–4 mCi). The patients were immobilized on the PET/CT table with a vacuum-assisted immobilizer bed before scan acquisition. Acquisition parameters for CT were 120 kVp tube voltage, 100 mA tube current, 0.8s rotation time. CT images were reconstructed in a 512×512 matrix with a slice thickness of 1.25 mm. PET acquisition time was 3 min, and images were reconstructed in a 128×128 matrix using an ordered subset expected maximization (OSEM) algorithm (24 subsets, 3 iterations).

Positron emission tomography/computed tomography-guided intervention planning

The reconstructed PET/CT images in DICOM format were sent to an automated robotic arm system workstation (ROBIO-EX, Perfint Healthcare Pvt. Ltd., Chennai, India) for biopsy planning. After reviewing the images, the course of needle trajectory was planned based on the lesion's tracer avidity and anatomical location. The robotic arm is positioned automatically to the planned path. The suitable biopsy needle was then inserted into the target lesion manually in a stepwise manner under strict surgical asepsis. To check the position of the needle with respect to the target lesion, low dose check CT scans were acquired. The axial FOV of these check CTs was limited to 40 mm (±20 mm of the plane containing the biopsy needle tip). The CT parameters for low dose check CT were 120 kVp, 50 mA, 0.8s rotation time. After confirming the needle position, samples were retrieved from the target lesion.

Internal radiation exposure measurement

Internal radiation exposure to the patient was due to the PET component of the PET/CT imaging. According to ICRP, the effective dose (E) is given by the summation of the product of absorbed dose to the organ (D_T) and its tissue weighing factor (w_T), $E = \Sigma_T W_T . D_T$. The absorbed dose to the organ or tissue from intravenous administration of an activity A of F-18-FDG or Ga-68-PSMA is given by $D_T = A . \Gamma$. The dose coefficients (Γ) provided by ICRP Publication 80 have been defined for various organs and tissues of the adult hermaphrodite MIRD phantom and are specific for every radiopharmaceutical.[18] The dose coefficient for Ga-68-PSMA was based on effective dose calculation done by Sandgren *et al*. using ICRP publication 103.[19] Thus, the effective dose for both F-18-FDG and Ga-68-PSMA was estimated as:

$$E = \Sigma_T w_T . D_T , = A . \ \Sigma_T w_T . \Gamma = A . \ \Gamma,$$

where, effective dose coefficient for F-18-FDG, $\Gamma^{FDG} = 0.703$ mSv/mCi (19 μSv/MBq) and that for Ga-68-PSMA is, $\Gamma^{Ga-68-PSMA} = 0.814$ mSv/mCi (22 μSv/MBq) and $= 1$, as given by ICRP publication 60.[20]

External radiation exposure measurement

External radiation exposure in PET/CT-guided intervention resulted from the CT component of the PET/CT imaging and the additional CT scans acquired to check the needle placement to the target lesion. The CT dose index (CTDIvolume) and dose length product (DLP) obtained from the CT dose report from the scanner console were noted to estimate the external radiation exposure. CTDI volume represents the dose within the scan volume from a particular scan protocol. DLP is the product of the CTDI volume and the axial scan length of the patient.[21] DLP obtained from the system (in mGy. cm) was converted into the effective dose (in mSv) using a set of coefficients (k) derived from NRPB (National Radiological Protection Board) Monte Carlo organ coefficients conversion factor.[22] The set of k coefficients depends on the region of the body scanned (head, neck, thorax, abdomen, and pelvis) and are defined for helical scans. Thus estimated effective dose, E (mSv) = k*DLP.

Statistical analysis

The data were described as mean ± standard deviation, and the percentage of contribution of CT and PET effective dose in total effective dose was calculated. The paired sample *t*-test was used to compare the mean values of CT and PET

effective dose in both F-18-FDG and Ga-68-PSMA guided intervention.

Results

A total of 101 (76 male and 25 female) patients aged 54.4 ± 16.2 (range 12–89) years were recruited in the study. F-18-FDG PET/CT-guided biopsies were done in 79/101 (78.2%) patients and Ga-68 PSMA PET/CT-guided biopsies in the remaining 22/101 (21.8%) patients. The sites of the biopsies were abdominal lesions (*n* = 17), thoracic lesions (*n* = 46), pelvic lesions (*n* = 36) and neck, and supraclavicular lesions (*n* = 2). Patients' characteristics are noted in Table 1.

For F-18-FDG PET/CT-guided biopsy procedure, the injected dose of F-18-FDG was 3.55 ± 1.45 mCi. The mean effective dose due to the PET component was 2.49 ± 1.02 (ranged 0.81–5.84) mSv. The mean effective dose due to the CT component was 2.35 ± 1.03 (ranged 0.76–5.69) mSv. The total mean effective dose for F-18-FDG PET/CT-guided biopsy procedures was 4.83 ± 1.90 (ranged 1.57–11.18) mSv [Table 2].

For Ga-68-PSMA-guided biopsy procedures, the injected activity of Ga-68-PSMA PET/CT was 1.98 ± 0.69 mCi. The mean effective dose due to the PET component was 1.60 ± 0.57 (ranged 0.91–2.74) mSv. The mean effective dose due to the CT component was 3.06 ± 1.36 (ranged 1.57–7.66) mSv. The total mean effective dose calculated for Ga-68-PSMA PET/CT-guided interventions was 4.66 ± 1.37 (ranged 2.8 mSv-9.38) mSv [Table 3].

During F-18-FDG PET/CT-guided biopsies, CT contributed 48.34% in total effective dose while PET contributed 51.66%. There was no significant difference between CT effective dose and PET effective dose (*P* = 0.12). During Ga-68-PSMA PET/CT-guided biopsy procedures, CT contributed 64.31% in total effective dose, and PET contributed 35.68%. A significant

Table 1: Patient characteristics and key variables

Parameter	Value
Total numbers of patients	101
Gender (male/female)	76/25
Age (years), mean±SD	54.4±16.2
Numbers of patients undergone FDG PET/CT guided biopsy (%)	79/101 (78.2)
Numbers of patients undergone PSMA PET/CT guided biopsy (%)	22/101 (21.8)
Sites of biopsy	
Thoracic lesions	46
Abdominal lesions	17
Pelvic lesions	36
Neck and supraclavicular lesion	2

SD: Standard deviation, FDG: Fluorodeoxyglucose, PET: Positron emission tomography, CT: Computed tomography, PSMA: Prostate-specific membrane antigen

difference in CT effective dose and PET effective dose values was noted (*P* < 0.001).

Discussion

PET/CT-guided intervention is a minimally invasive and efficient diagnostic modality. Lesions characterized by metabolic information have a higher biopsy success rate than that characterized by anatomical information alone.[23,24] In the case of intervention studies, the patient is exposed to more number of CT scans than in routine procedures. Additional CTs are required for accurate guidance to the performing physician and to prevent complications such as damage to the surrounding organs. The repeated exposure of the same region of the patient's anatomy raises the concern of radiation exposure to the patients undergoing PET/CT-guided intervention.

Many studies show the diagnostic efficacy of PET/CT-guided biopsy, but very few attempts have been made to measure radiation exposure to the patients.[3-7,25-27] A single-pilot study (*n* = 9) has been reported by Tatli *et al.* on the radiation exposure to patients undergoing PET/CT-guided interventions.[6] The radiation exposure computed by Tatli *et al.* was only due to the CT component. However, radiation exposure to patients undergoing any PET/CT procedure results from both the PET component, i.e. the radioactivity injected and the CT component. To our knowledge, this is the first study done to evaluate the radiation exposure to patients undergoing PET/CT-guided biopsy due to both PET and CT components.

The mean CT exposure reported in the study reported by Tatli *et al.* was quite high (8.2 mSv, 3.5–15.2 mSv) compared to the present study. It is because of the use of a higher tube voltage of 140 kV than tube voltage of 120 kV in the present study.

The mean effective dose due to the CT component in the present study was also less when compared to the CT effective dose received during the CT-guided biopsies. The effective dose during CT-guided interventional procedures computed by Guberina *et al.* on two different scanners was 7.3 mSv and 11.4 mSv, 9.3 mSv and 13.9 mSv, 6.3 mSv and 7.4 mSv, 4.3 mSv and 10.3 mSv for chest, abdomen, spine, and extremities, respectively.[28] Leng *et al.* also reported a mean effective dose of 13.8 ± 9.2 mSv in different interventional CT procedures.[29] However, the effective dose in the present study due to CT component and the total effective dose was found to be very less 2.36, 2.40, 2.36, 1.64 mSv and 4.91, 4.80, 4.82, 3.38 mSv for thorax, abdomen, pelvis, and neck, respectively.

The present study also evaluated the radiation exposure due to the PET component in Ga-68-PSMA and F-18-FDG-guided biopsies. The dose coefficient for Ga-68-PSMA is higher than that for F-18-FDG; however, the effective dose due to the PET component in F-18-FDG studies was higher than those in Ga-68-PSMA

Table 2: The key variable for F-18-fluorodeoxyglucose positron emission tomography/computed tomography guided biopsy (*n*=79)

	Mean±SD (range)			
	The injected activity of FDG (mCi)	Effective dose due to CT component (mSv)	Effective dose due to PET component (mSv)	Total effective dose (mSv)
Thorax (*n*=46)	3.65±1.45 (1.63-8.34)	2.36±1.00 (1.08-5.69)	2.56±1.01 (1.14-5.84)	4.91±1.87 (2.22-11.18)
Abdomen (*n*=17)	3.43±1.54 (1.15-7.66)	2.40±1.19 (0.76-5.31)	2.40±1.08 (0.81-5.36)	4.80±2.01 (1.57-10.41)
Pelvis (*n*=14)	3.51±1.37 (2.00-7.10)	2.36±1.95 (1.29-4.69)	2.46±0.96 (1.40-4.97)	4.82±1.87 (2.72-9.66)
Neck (*n*=2)	2.48±0.73 (1.75-3.22)	1.64±0.48 (1.16-2.12)	1.74±0.51 (1.23-2.25)	3.38±1.00 (2.38-4.37)
Total (*n*=79)	3.550±1.45 (1.15-8.34)	2.35±1.03 (0.76-5.69)	2.49±1.02 (0.81-5.84)	4.83±1.90 (1.57-11.18)

SD: Standard deviation, FDG: Fluorodeoxyglucose, PET: Positron emission tomography, CT: Computed tomography

Table 3: The key variable for Ga-68-prostate-specific membrane antigen positron emission tomography/computed tomography guided biopsy (*n*=22)

	Mean±SD (range)			
	The injected activity of Ga-68 PSMA (mCi)	Effective dose due to CT (mSv)	Effective dose due to PET (mSv)	Total effective dose (mSv)
Pelvis (*n*=22)	1.98±0.69 (1.12-3.36)	3.06±1.36 (1.57-7.66)	1.60±0.57 (0.91-2.74)	4.66±1.37 (2.8-9.383)

SD: Standard deviation, PET: Positron emission tomography, CT: Computed tomography, PSMA: Prostate-specific membrane antigen

patients. It is because the mean injected activity for F-18-FDG (3.55 ± 1.45 mCi) was higher than that for Ga-68-PSMA (1.98 ± 0.69 mCi). However, the effective dose due to the CT component was almost the same in both cases as CT parameters were similar in both the procedures. No such study comparing the effective dose to patients undergoing Ga-68-PSMA and F-18-FDG-guided biopsies has been reported so far.

The mean effective dose in F-18-FDG PET/CT whole-body procedure is 18–25 mSv[30-33] and for Ga-68-PSMA is 18–21 mSv.[18,33] The mean effective dose in PET/CT-guided biopsies in F-18-FDG and Ga-68-PSMA was much less, i.e., 4.83 mSv and 4.66 mSv, respectively. The difference in mean effective dose from PET component in whole-body studies and biopsy procedure is due to difference in activity administered. In the case of biopsy procedures, the image quality is not the concern, so activity as low as 3 mCi in the case of F-18-FDG and 1 mCi in Ga-PSMA can be administered. The contribution of the CT component to an effective dose in F-18-FDG PET/CT whole-body studies is generally higher than the PET component, estimated to be 54%–81%.[31] This is because of the use of higher tube current and more photon flux in CT. In the present study, the effective dose contributed by both CT and PET components was compared. The effective dose due to the CT component was reduced by a substantial factor than the whole-body scan due to a smaller tube current. The CT component's contribution was still higher than the PET component in Ga-68-PSMA biopsies because of the lower mean activity of Ga-68-PSMA injected. The dose contribution due to CT and PET components was found to be similar in the case of F-18-FDG-guided interventions. It resulted from the patients who underwent F-18-FDG PET/CT whole-body scan and biopsy on the same day. Such patients were injected with higher activity of F-18-FDG

activity than lower activity in PET/CT guided biopsies. This resulted in a higher mean value of activity injected and a higher effective dose due to the PET component. However, the contribution by both PET and CT components may vary from one procedure to another.

Many factors resulted in increased radiation exposure to patients, such as patient motion during the biopsy procedure, noncooperative patients, spontaneous breathing during abdominal procedures, leading to needle misalignment. The present study also observed that exposure to patients was more in abdominal procedures than pelvic, thorax, or neck procedures. In the case of abdominal biopsies, the lesion was targeted in multiple passes due to the needle movement resulting from respiratory or bowel movement. As a result, multiple check CT scans were acquired to check the needle position in the lesion, leading to higher exposure to the patients.

As per this study, radiation exposure to a patient undergoing PET/CT-guided biopsies can be reduced by taking care of certain factors. It is known that radiation exposure due to the CT component is directly proportional to the CT tube current. The routine whole-body PET/CT study uses CT tube current (100–350 mA), however reducing the CT tube current to 40–50 mA is good enough to visualize the position of the biopsy needle with respect to organs, substantially reduced the radiation exposure to the patient. Furthermore, the axial field of view was confined to few millimeters instead of routine 15.6 cm, reducing the value of DLP and, in turn, the value of the effective dose. Another important factor is patient motion; patient movement during the procedure leads to the need to acquire serial, repetitive check CT scans to localize the needle in the target site, resulting in increased radiation exposure. Hence, instructing patients not to move before the study can reduce

the patient's motion and radiation exposure. To reduce the exposure due to the PET component, it is advisable to perform PET/CT guided on the same day of the whole body study. If patients had already undergone PET/CT study once, the activity injected for PET/CT-guided biopsy was reduced to as low as 2-3 mCi (74–111 MBq).

According to ICRP 103, there is no limit to radiation exposure prescribed to patients, but it needs to be justified.[34] While achieving diagnostic efficacy, the benefit should outweigh the harm. The exposure to patients from PET/CT guided biopsy is minimal compared with other procedures such as fluoroscopy and CT.

The present had few limitations. First, both internal and external radiation exposures were estimated but not the actual exposure. Second, the internal radiation exposure for F-18-FDG and Ga-68-PSMA for "Reference Man" was not normalized for the individual patients. Third, the external radiation exposure was estimated using CTDIvol and DLP is given by the scanner. The scanner-provided CTDIvol and DLP estimates are based on circular uniform phantom geometry, and so the actual patient doses could vary by 5%–41% based on body habitus.[35]

Conclusion

PET/CT-guided biopsy is an emerging technique for individualized patient management. The fear of radiation exposure to patients during the procedure should not be considered as a limiting factor. Our analysis demonstrated that the effective dose for patients undergoing PET/CT guided biopsies was 4.83 mSv, much less than routine PET/CT studies. Using CT dose reports and the dose coefficient of PET radiopharmaceutical is quite a practical and easy approach to estimate the radiation exposure to the patients undergoing PET/CT guided biopsies.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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